Extreme marine heatwave off southeastern Australia in austral summer 2015-2016

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Marine Heatwave Definition

- A **marine heatwave (MHW) definition** has been proposed (Hobday et al., 2016)
- A MHW is defined to be **a discrete prolonged anomalously warm water event at a particular location**
  - **'anomalously warm'**: MHW temperatures are above a baseline 90^{th} percentile climatology
  - **'prolonged'**: a MHW must persist for at least 5 days
  - **'discrete'**: a MHW event has well-defined start and end times

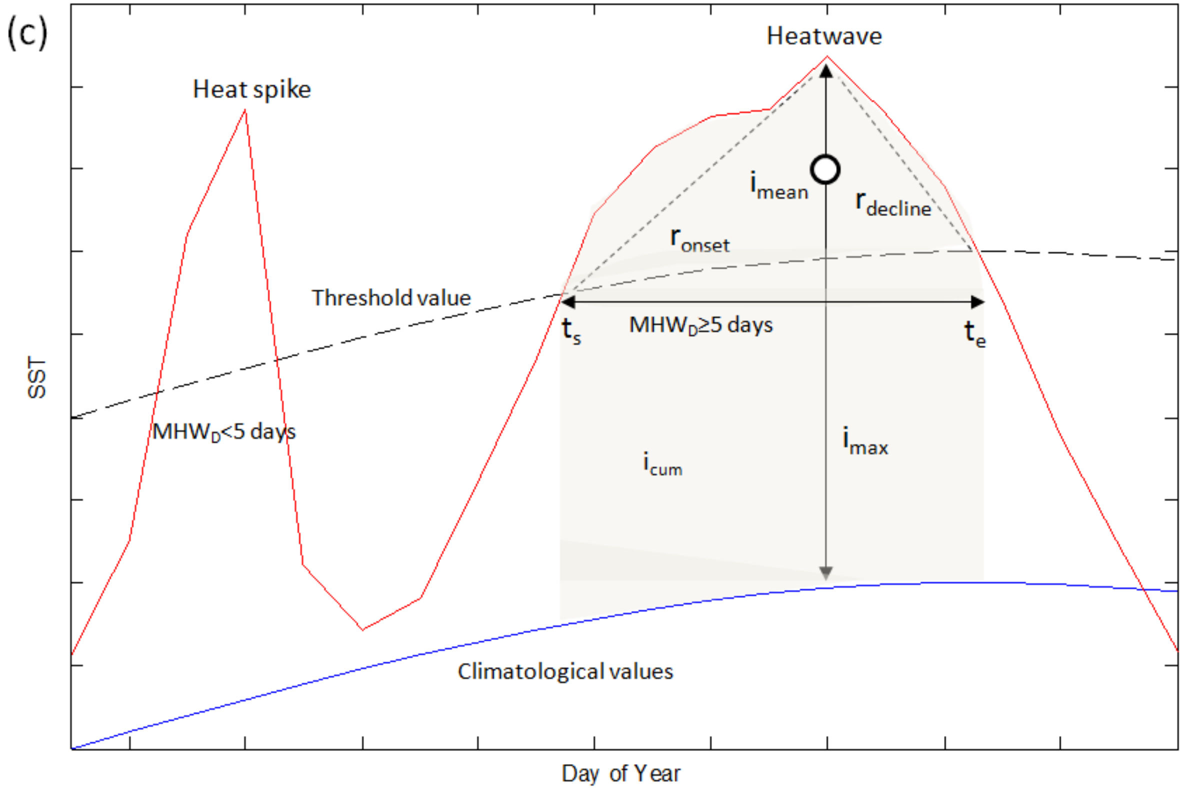


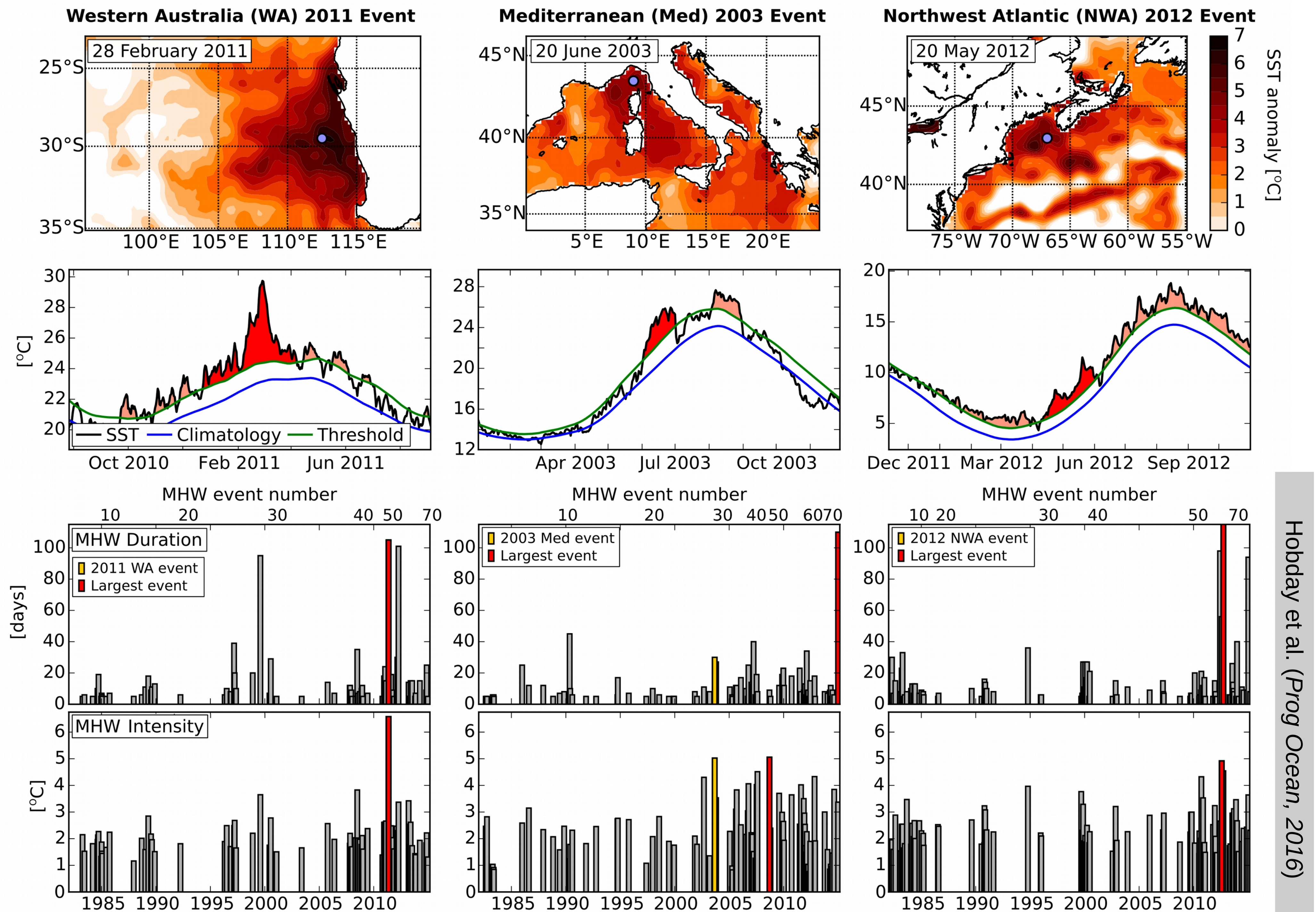
Figure from Hobday et al. (2016) *Prog. Ocean.*

Definition includes a set of metrics, including:

- **Intensity** [°C]
  - both maximum and event-mean
- **Duration** [days]
  - Time from start to end dates

Software implementation in Python freely available here:
`github.com/ecjoliver/marineHeatWaves`

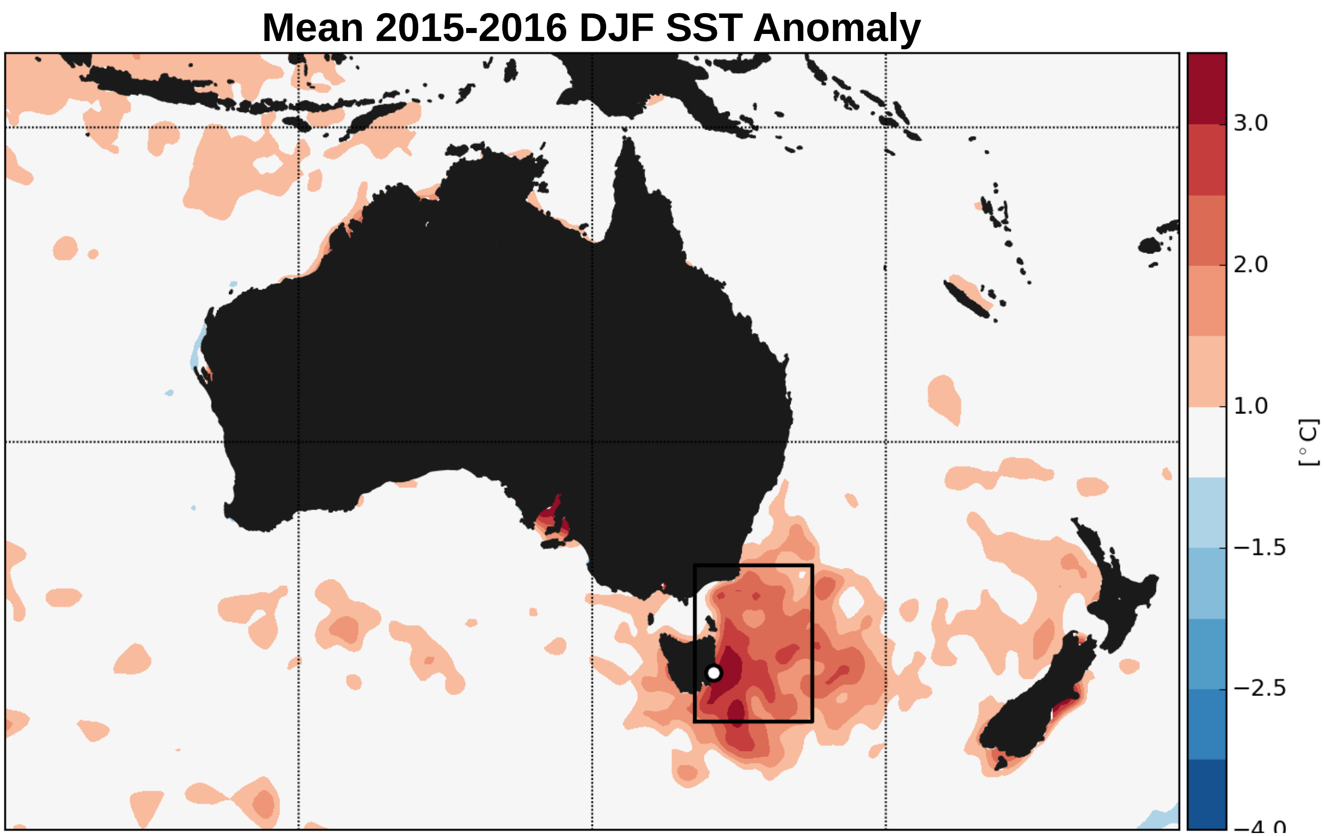
Can **identify historical events** from the observational record (satellite SST measurements: NOAA OI SST)

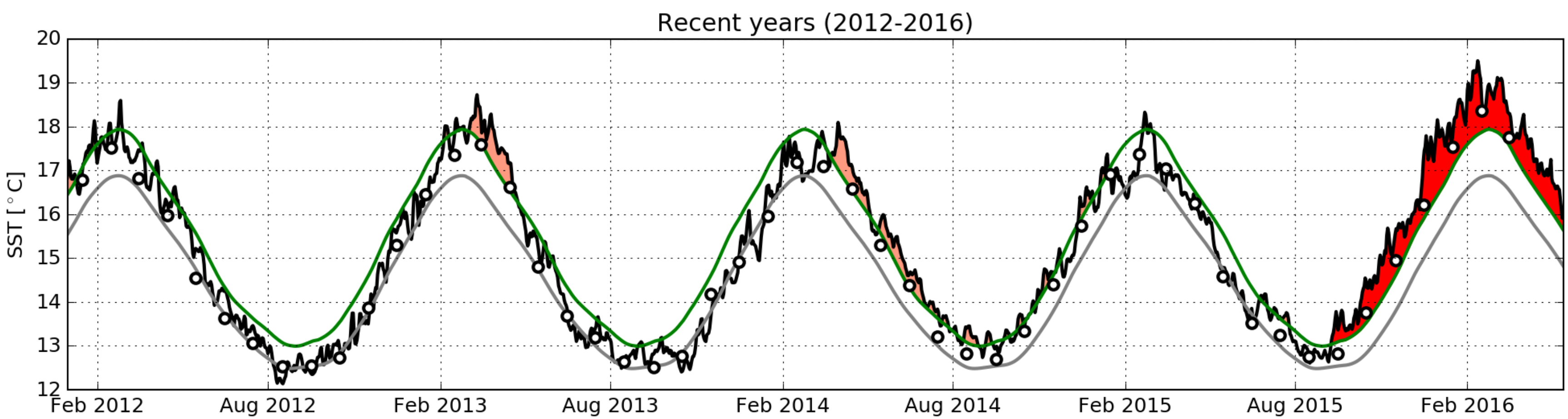


Hobday et al. (*Prog Ocean, 2016*)

2015-2016 SE Australia MHW

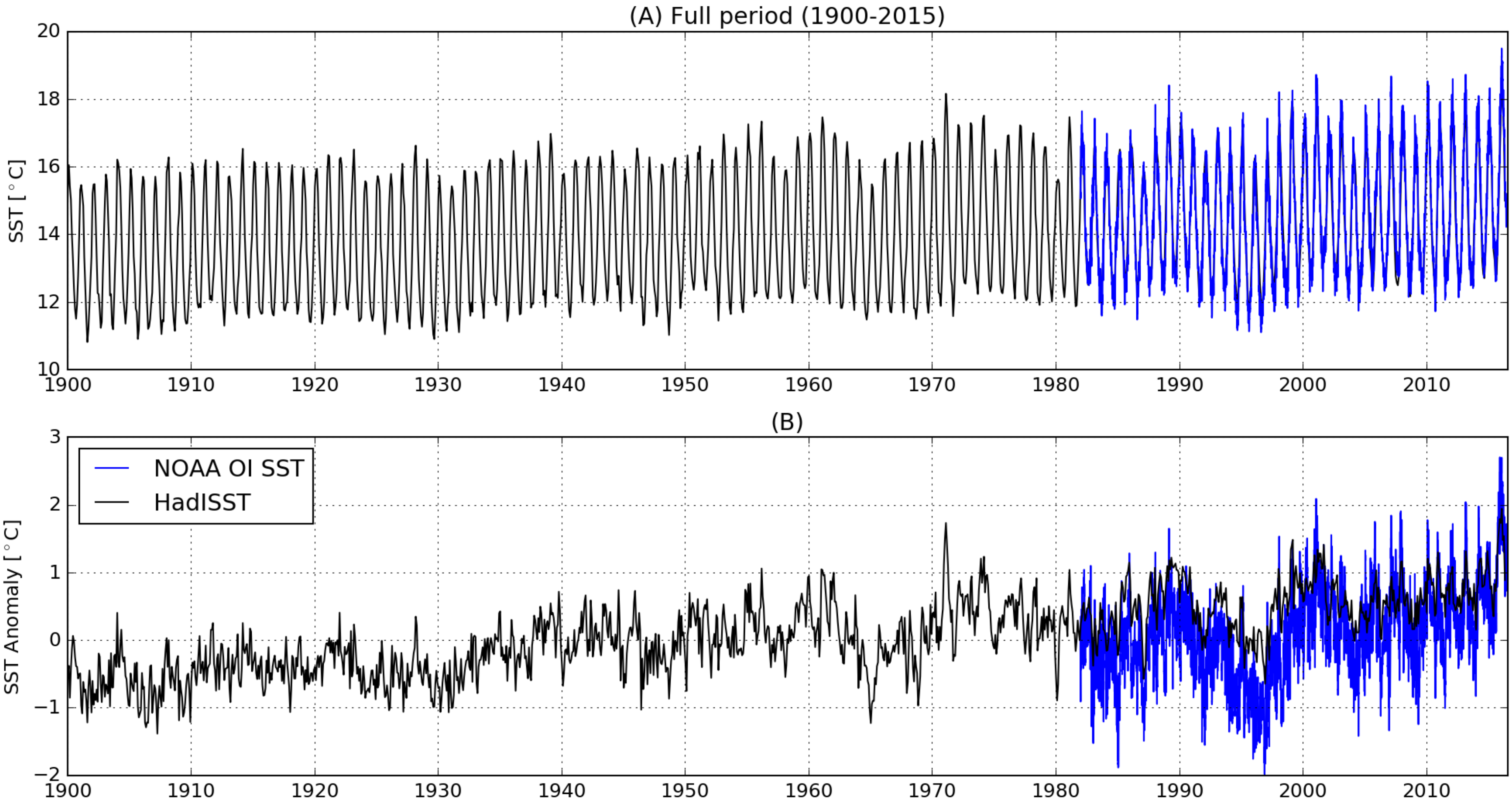
- There was a **marine heatwave** that occurred this **past summer** off southeastern Australia (9 Sep 2015 – 17 May 2016)
- It is unprecedented in
  - **Duration (252 days)**
  - **Intensity (2.7°C max)**
- **Impacts**: POMS (Oysters), dead abalone, poor salmon farm performace, strange fish intrusions, kelp thinning…
- Currently developing framework to **report and understand** these events in **near-real time**.





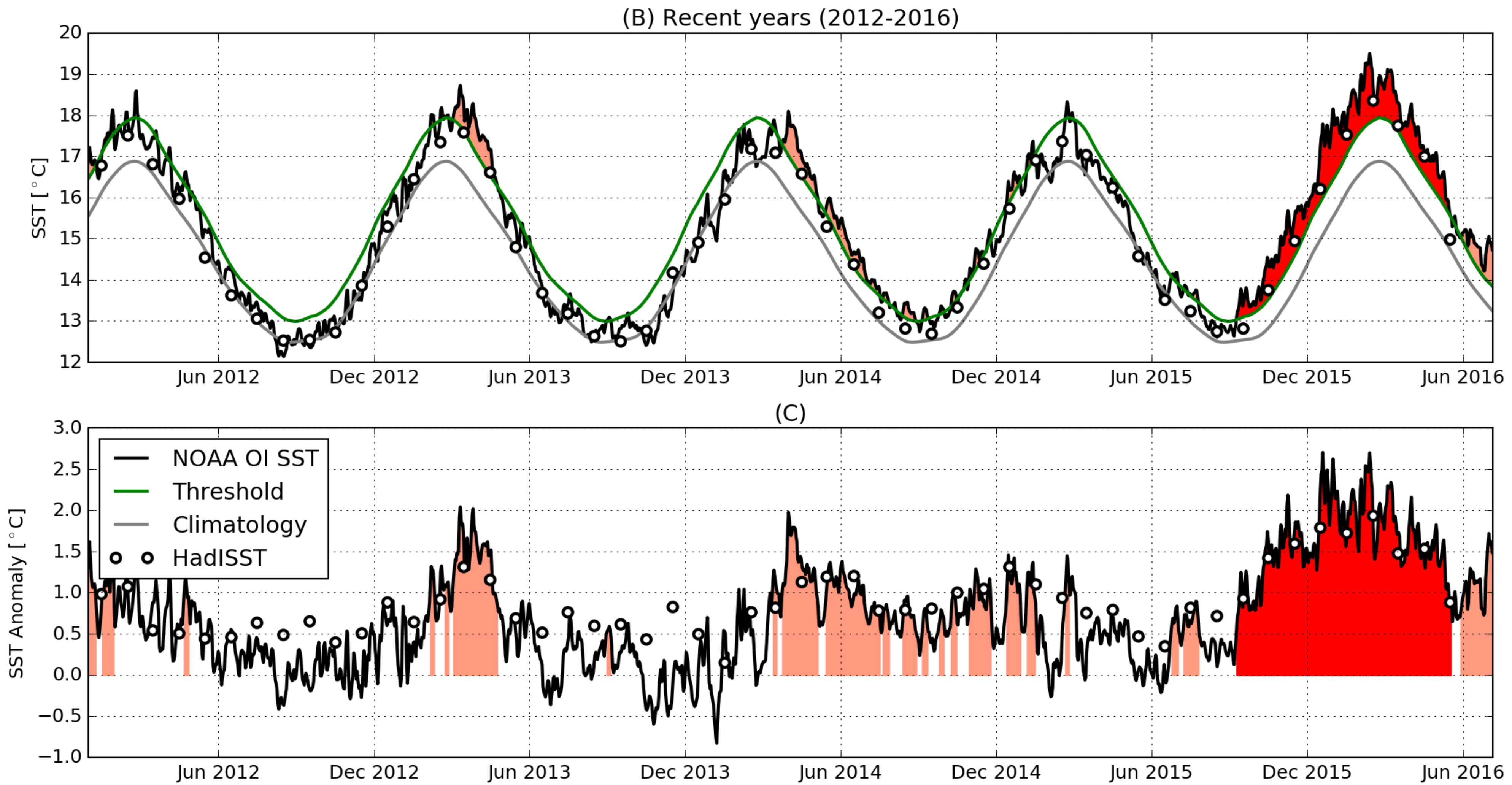
SST Observations

- Largest SST (absolute and anomaly) recorded since 1982 (satellite) and 1900 (HadISST)



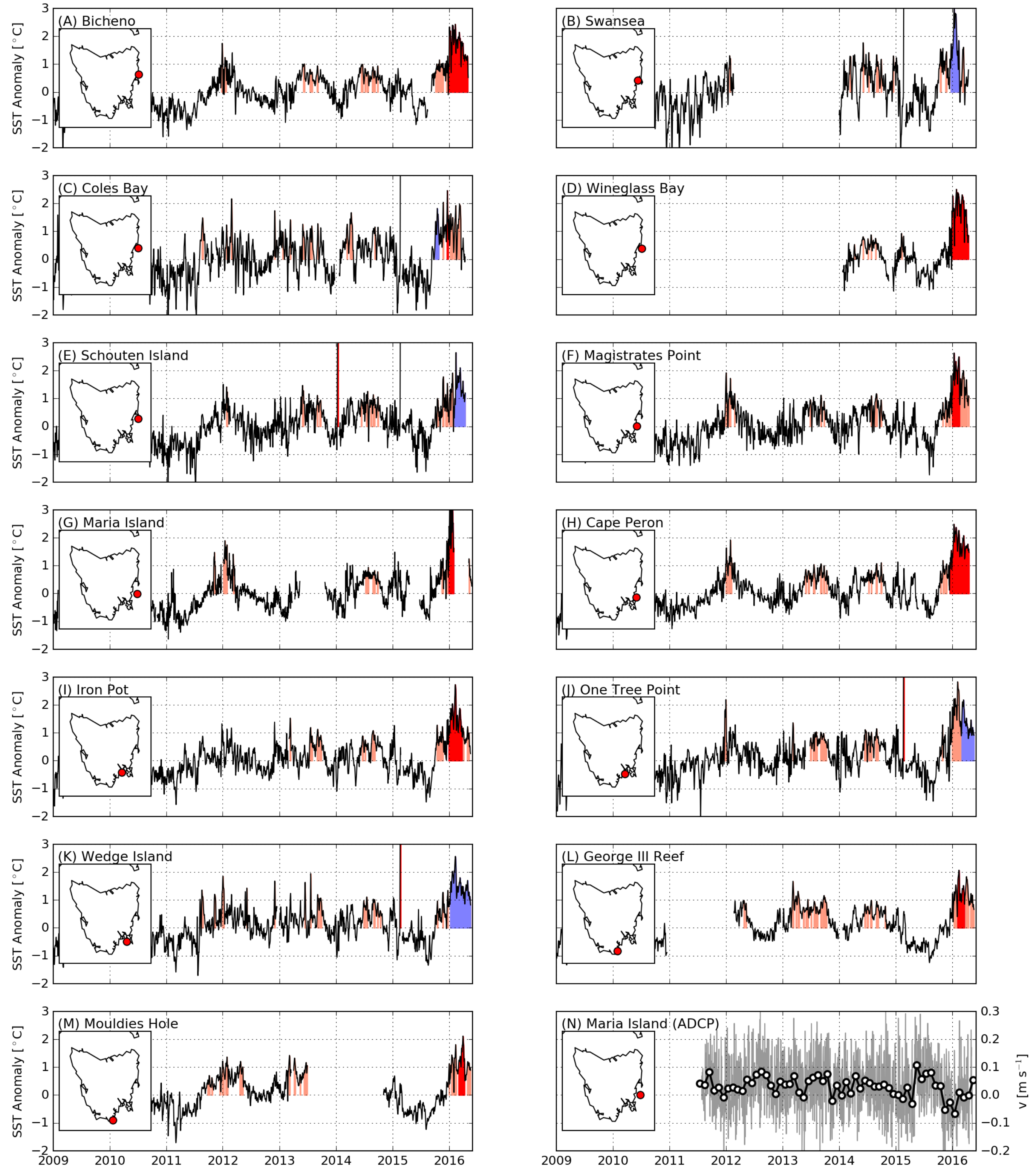
SST Observations

- Peak anomalies over 2.5°C, marine heatwave state lasted for 252 days (NOAA OI SST)
- 6 of the 9 months were the largest HadISST anomalies on record
- Largest run of 9-month HadISST anomalies on record



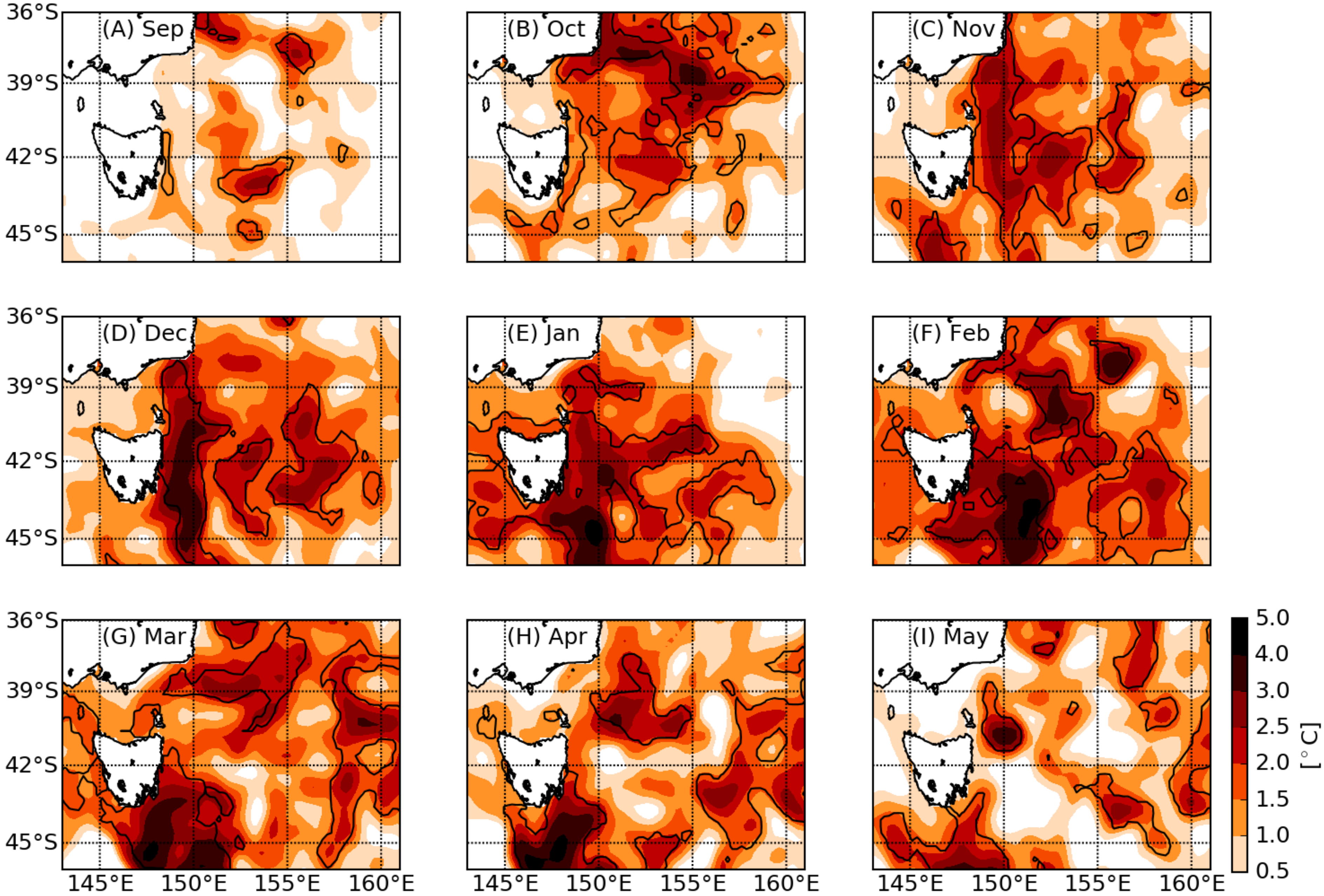
Nearshore Records

- A number of **nearshore sites** in **6-20 m depth**
- This event was **record strength** (approx. 10 year records) in the coastal zone
- Record **southward flows**, possible indication of **forcing mechanism**



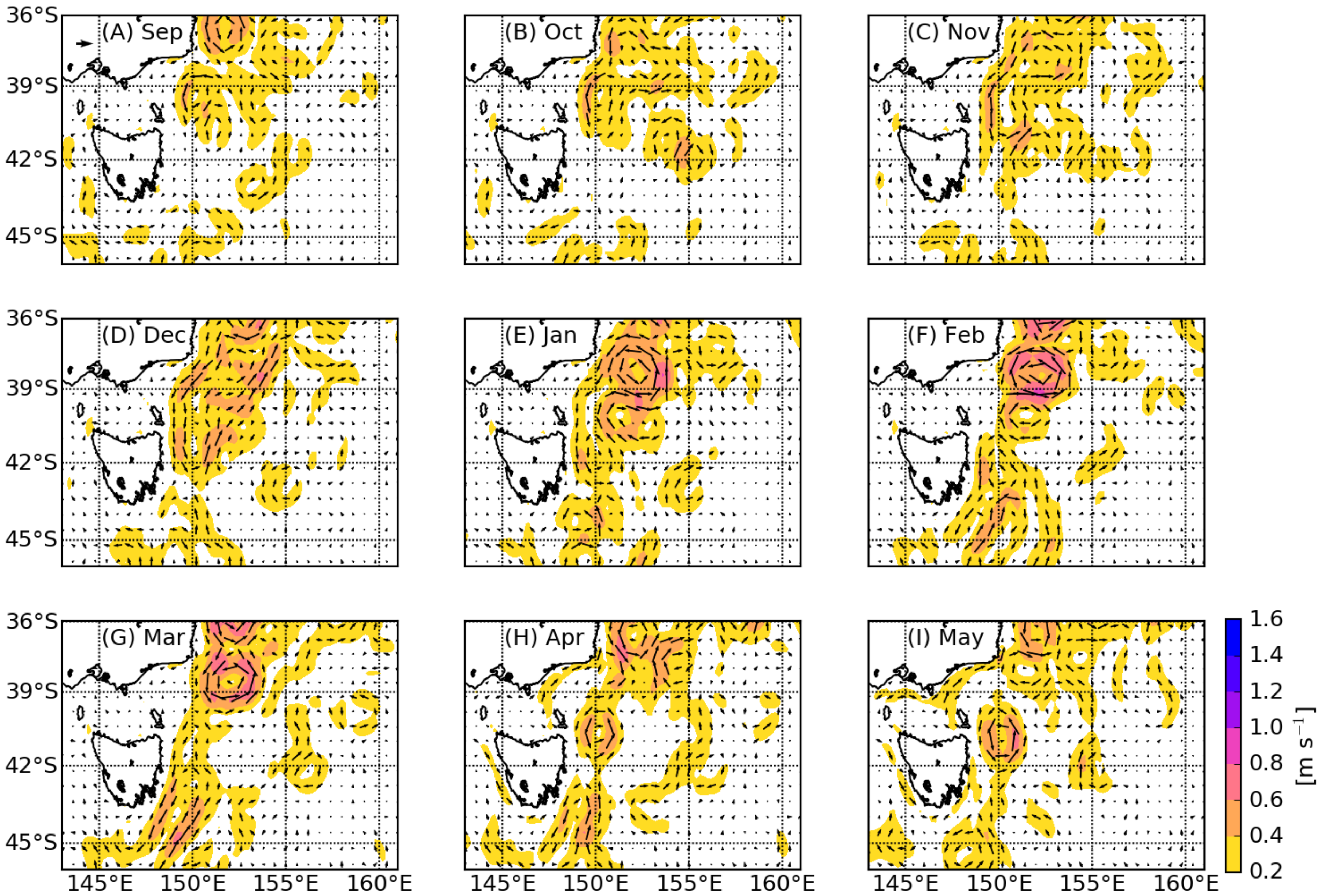
Evolution of the event

Monthly SST anomalies: contour encloses areas that were detected as MHWs for >90% of that month



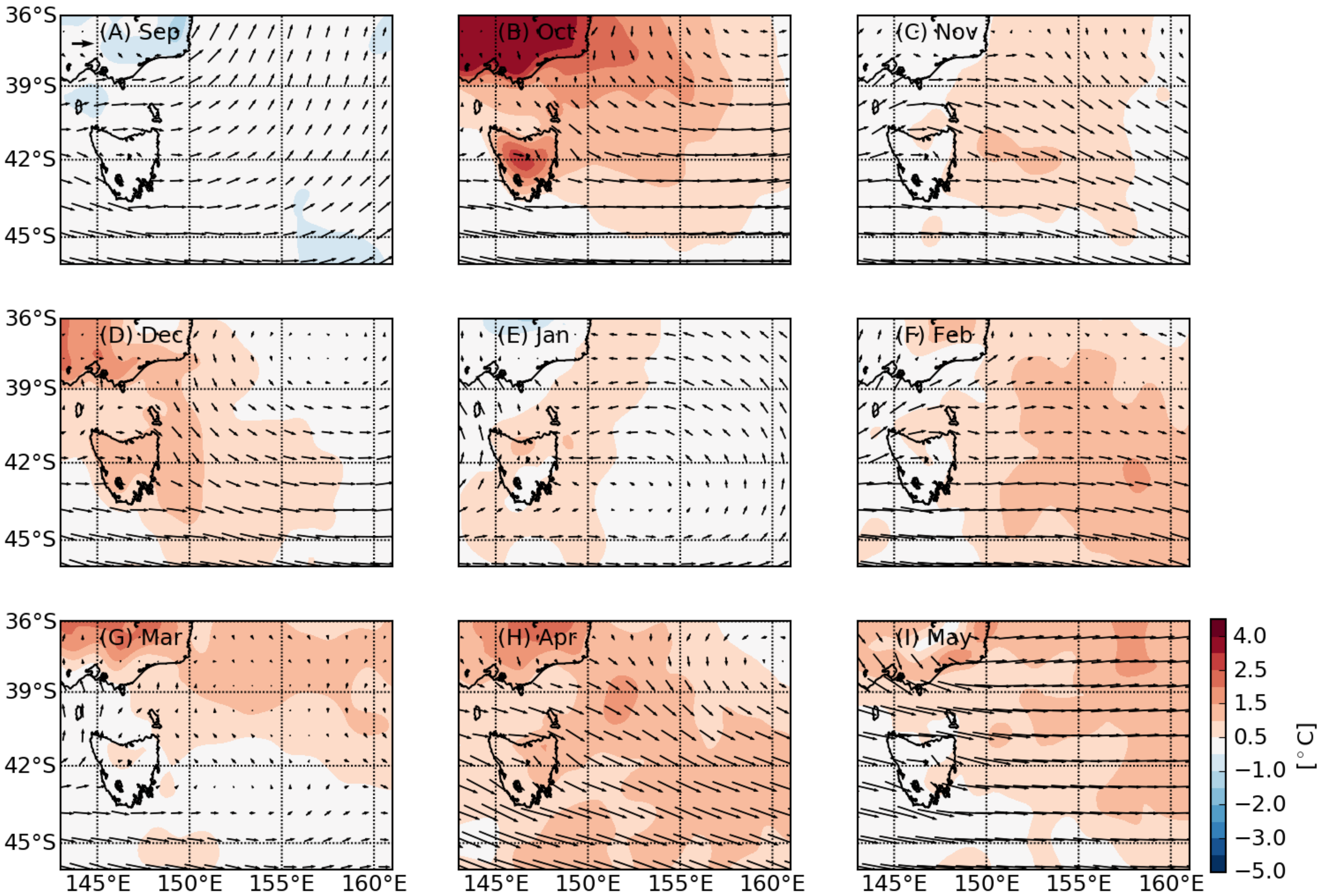
Evolution of the event

Monthly surface currents (u, v) (IMOS OceanCurrent)



Evolution of the event

Monthly SAT and 10 m wind anomalies (NCEP CFSv2)



Physical drivers

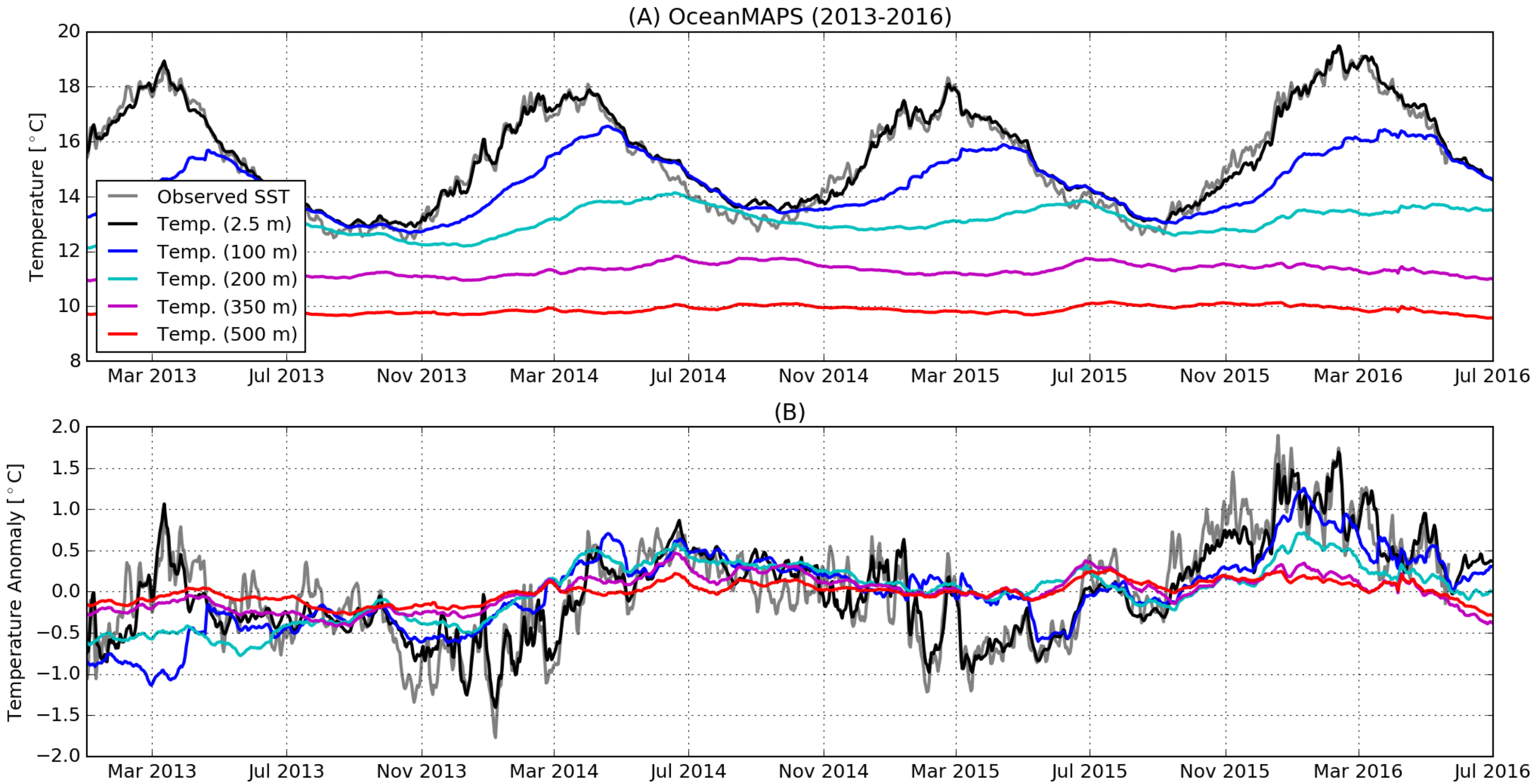
- **<u>Upper ocean temperature budget</u>**, following:
  - Benthuysen et al. (*CSR*, 2014) for 2011 WA MHW
  - Chen et al. (*JGR*, 2015, 2016) for the 2012 NW Atlantic MHW
- Volume averaged temperature tendency equation:

$$\frac{dT}{dt} = \underbrace{-u_{\mathrm{H}} \cdot \nabla_{\mathrm{H}} T}_{\text{Horizontal temperature advection}} + \underbrace{\frac{1}{A} \int_{\mathrm{A}} \frac{Q}{\mathrm{H}} dA}_{\text{Air-sea heat flux}} + \underbrace{\mathrm{Residual}}_{\text{Includes: Horizontal and vertical diffusion, vertical advection}}$$

- Depth: H = 100 m
- Area: A = "SEAus box"
- Temperature (T) and velocities (u_H) from OceanMAPS
- Surface heat flux (Q) from NCEP CFSv2 reanalysis

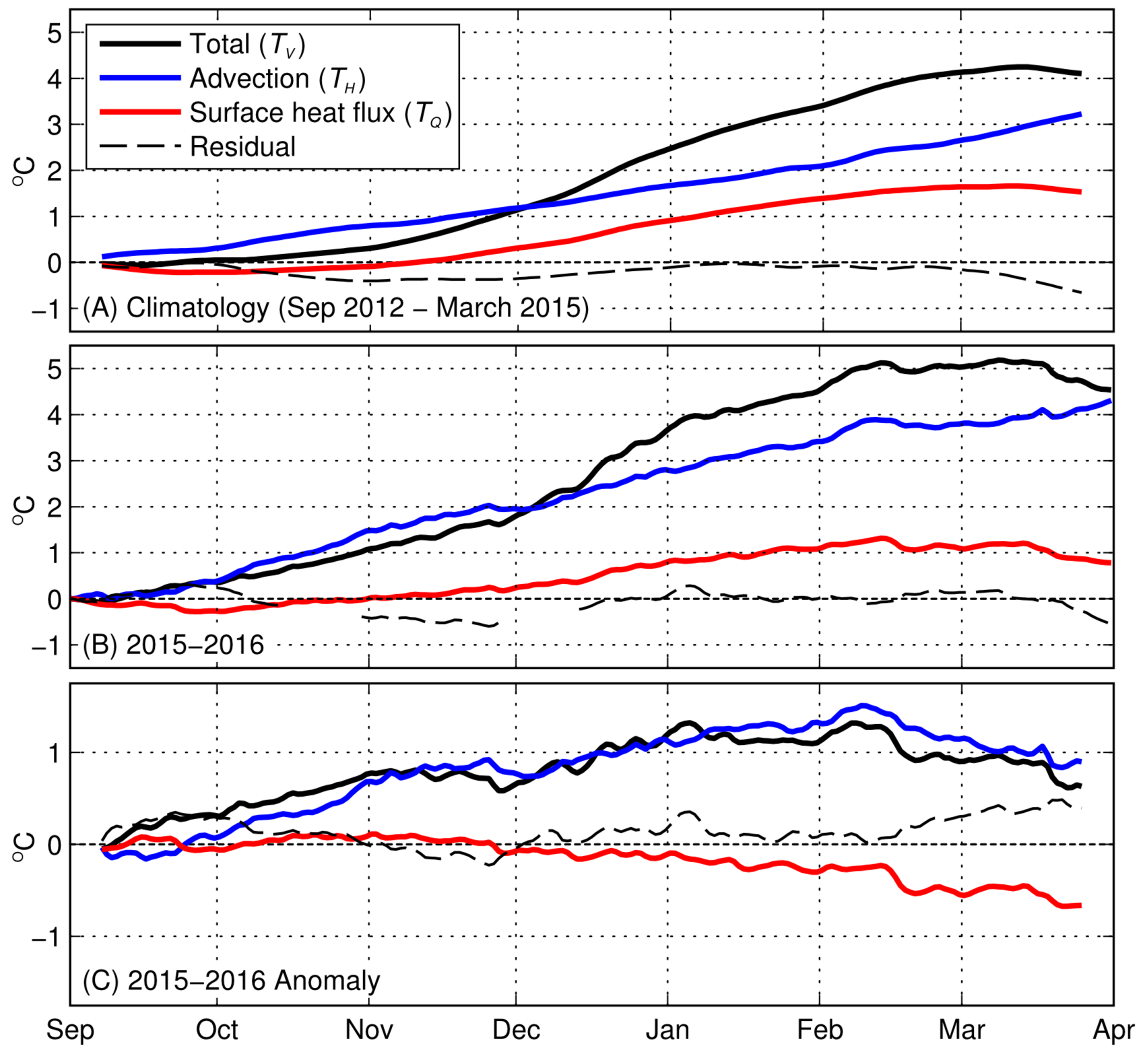
Physical drivers

- **How well does OceanMAPS get the temperature?**
- Good agreement at surface → we can trust OceanMAPS
- Warming evident down to 100-200 m → *H* = 100 m



Physical drivers

- **<u>Temperature budget</u>**
- Volume averaged temperature (T_V) since Sep 1st of:
  - 2012, 2013, 2014, 2015
- Consider:
  - Temperature avection (T_H)
  - Air-sea heat flux (T_Q)
- <u>Climatology</u>: by mid-February T_H contributes ~3/5 of the warming while T_Q contributes ~2/5
- <u>2015-2016</u>: by mid-February T_H contributes ~4/5 of the warming while T_Q contributes ~1/5
- Marine heatwave primarily driven by **anomalous temperature advection**



Role of climate change

- **<u>Event Attribution study</u>** following
  - Lewis & Karoly (*GRL*, 2013) on Australia's "angry summer" of 2013
  - King et al. (*ERL*, 2015) on Central England temps. of 2014
- Calculate *Fraction of Attributable Risk (FAR)*:

$$\mathrm{FAR} = 1 - \frac{P_{\mathrm{histNat}}}{P_{\mathrm{hist}}}$$

  where P_X is the probability of an the event larger/longer than the event in question based on model climate *X*.

- Basically can tell us the change in likelihood of occurrence of an event like the event in question due to anthropogenic influence (hist) as opposed to a natural-forced world (histNat)
- Look at SEAus MHWs in CMIP5 historical, historicalNat and RCP8.5 runs

Role of climate change

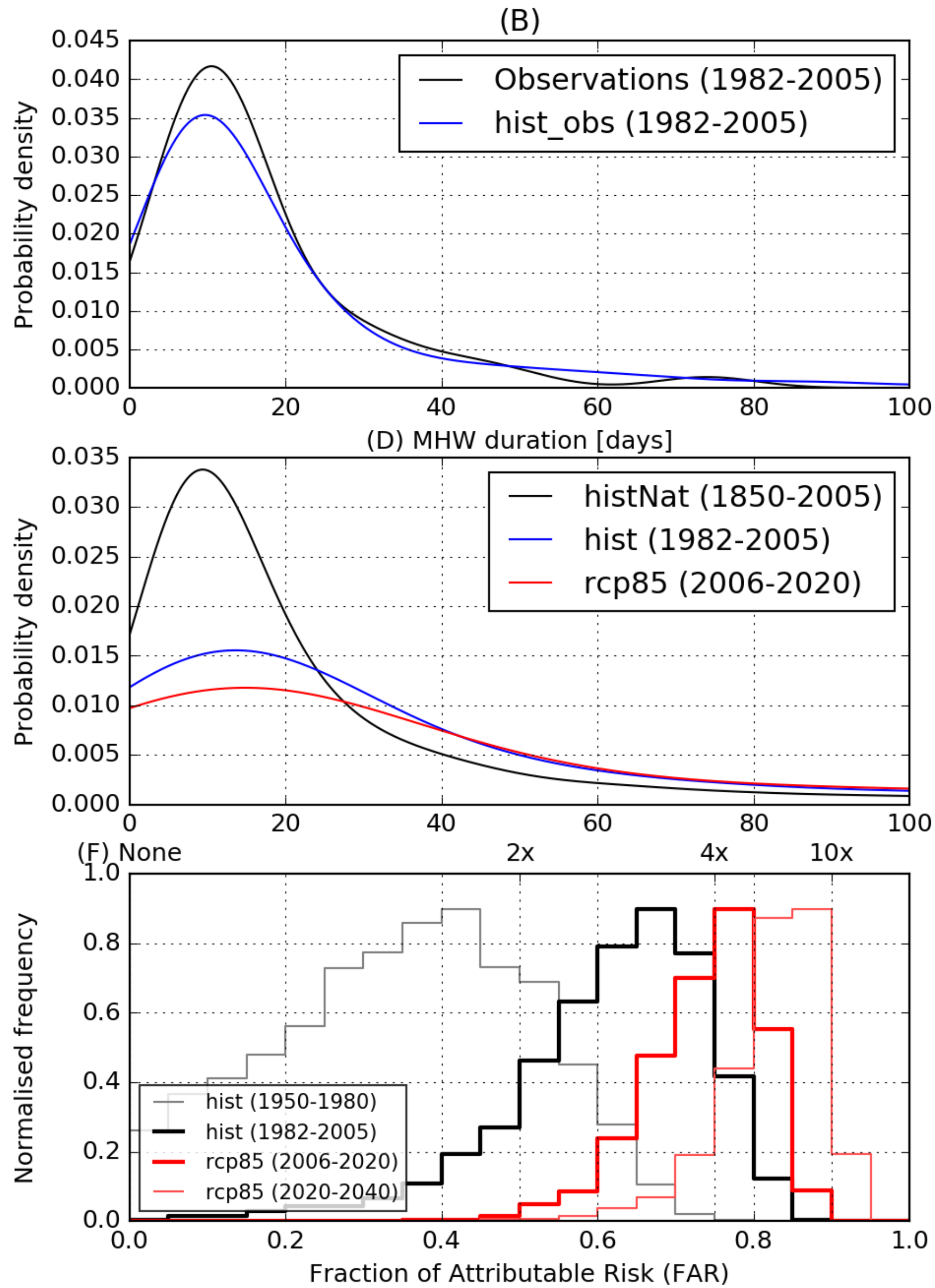
- Need *daily* SSTs, limits the number of available models:

Model	Historical	HistoricalNat	RCP8.5	Bias correction
ACCESS1.3	3	3	1	1.32
CSIRO Mk3.6.0	10	10	10	1.42
CNRM-CM5	1	5	5	0.80
HadGEM2-ES	4	4	4	0.96
IPSL-CM5A-LR	6	3	4	0.98
IPSL-CM5A-MR	3	3	1	0.91
Total	**27**	**28**	**25**	-

- Rather than do model selection (so few to begin with) we did a bias correction
- Decompose SST time series as follows: $T_t = a + bt + T_t^{\mathrm{S}} + T_t'$
- Isolate linear trend ($a + bt$) and seasonal cycle (T^{S}_t) by regression, compare variance of non-seasonal variability (T'_t) between obs and model hist runs as a ratio
- Scale variance of each model run based on the calculated bias, then add it back to the linear and seasonal component

Role of climate change

- **<u>Attribution statement</u>** made separately around 2nd-largest (intensity) and 2nd-longest (duration) event:
  - 2.2 °C
  - 84 days
- **<u>Duration</u>**: An event of this duration was
  - **2.7x as likely** in 1982-2005 (hist simulations) compared to the "natural world" (historicalNat 1850-2005 simulations)
  - **4x as likely** by 2006-2020 (RCP8.5 simulations)



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  - **2.7x as likely** in 1982-2005 (hist simulations) compared to the "natural world" (historicalNat 1850-2005 simulations)
  - **4x as likely** by 2006-2020 (RCP8.5 simulations)
- **<u>Intensity</u>**: An event of this intensity was
  - **1.9x as likely** in 1982-2005 (hist simulations) compared to the "natural world" (historicalNat 1850-2005 simulations)
  - **2.5x as likely** by 2006-2020
- → Virtually certain (>99%) that anthropogenic climate change increased the likelihood of an event of this duration or intensity by 2005-2020